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TECHNICAL REPORT NO. 66-67

DEEP-HOLE SYMMETRICAL TRIAXIAL SEISMOMETER, MODEL 22700

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TELEDYNE INDUSTRIES
GEOTECH DIVISION
GARLAND TEXAS

TECHNICAL REPORT NO. 66-67

DEEP-HOLE SYMMETRICAL TRIAXIAL SEISMOMETER, MODEL 22700

by

Richard M. Shappee

Sponsored by

Advanced Research Projects Agency
Nuclear Test Detection Office
ARPA Order No. 624

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TELEDYNE INDUSTRIES
GEOTECH DIVISION
3401 Shiloh Road
Garland, Texas

22 June 1966

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ABSTRACT

A deep-hole symmetrical triaxial seismometer was designed, laboratory tested, and field tested. The results of tests showed that the instrument met the design objectives and was ready for additional field testing and use.

DEEP-HOLE SYMMETRICAL TRIAXIAL SEISMOMETER, MODEL 22700

1. INTRODUCTION

1.1 PURPOSE

This report describes a deep-hole, short-period, triaxial seismometer that was originally designed under Project VELA T/072, and that was improved and operated in Project VELA T/5051. Design features, laboratory tests, and field tests are discussed.

1.2 AUTHORIZATION

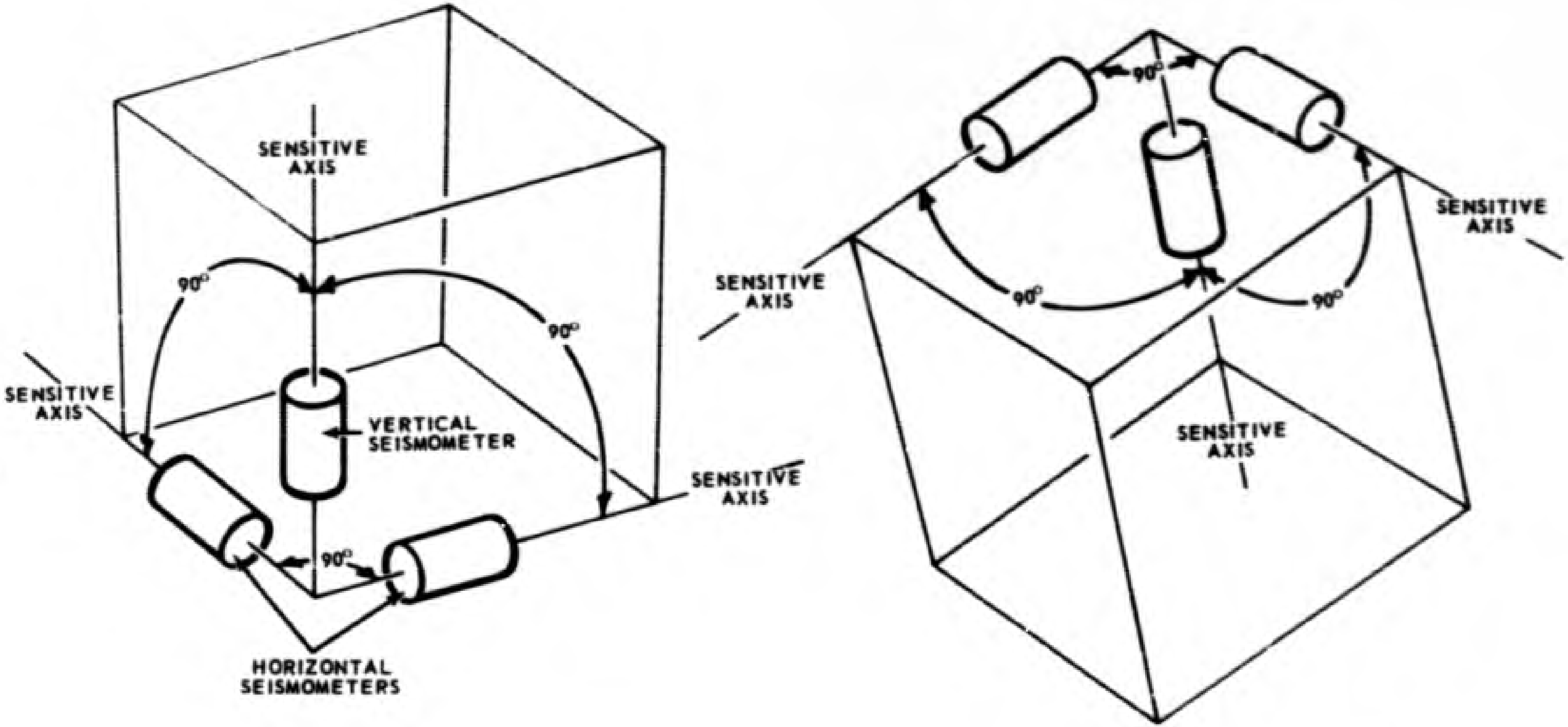
The work described in this report was done in partial fulfillment of the requirements of Task 1b, Project VELA T/5051, Contract AF 33(657)-13668. The project is under the technical direction of the Air Force Technical Applications Center (AFTAC) and under the over-all direction of the Advanced Research Projects Agency (ARPA).

2. BACKGROUND

Seismic measurements are customarily made with a three-component seismograph in which the sensitive axes of the seismometers are mutually perpendicular. Two of the seismometers are placed in a horizontal plane, with their sensitive axes horizontal and the third seismometer is operated with its sensitive axis vertical. The seismometers can be made to have similar phase and amplitude responses, but because two distinctly different types of instruments are used (horizontal and vertical), it is reasonable to expect that some differences will exist in their phase and amplitude responses.

In a triaxial seismometer, the sensitive axes are mutually perpendicular, but the planes of reference are rotated. Figure 1 illustrates both the conventional three-component seismometer and the triaxial seismometer. Because the triaxial seismometer consists of three identical elements, the phase and amplitude characteristics of the three elements can be expected to be more closely matched than those of conventional three-component seismographs.

When the electrical outputs of the three modules are properly combined, the triaxial seismometer will provide outputs equivalent to the outputs of a



CONVENTIONAL SEISMOGRAPH INSTRUMENTS ARE MUTUALLY PERPENDICULAR, TWO INSTRUMENTS HORIZONTAL, ONE INSTRUMENT VERTICAL

TRIAXIAL SEISMOGRAPH INSTRUMENTS ARE MUTUALLY PERPENDICULAR. ALL INSTRUMENTS ARE SENSITIVE ALONG AN AXIS 35° 18' FROM HORIZONTAL.

Figure 1. Conventional three-component seismometer and triaxial seismometer

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conventional three-component set of seismometers (two horizontal seismometers and a vertical seismometer). Also, by proper summation of the outputs, the sensitive axes of the instrument may be electrically rotated without need for physical rotation of the seismometer. A Coordinate Transformer, Geotech Model 16432, can be used to provide means of adding the outputs or electrically rotating the system.

3. INSTRUMENT DESCRIPTION AND SPECIFICATIONS

3.1 INSTRUMENT DESCRIPTION

The triaxial seismometer, shown in figure 2, is composed of three identical seismometer modules, a hole lock, a remotely operated switch, and a cable connector.

The seismometer modules are all identically constructed with a locating tongue and socket as an integral part of the electrical connectors so that assembly of any three modules will produce a system with the axes properly oriented, with respect to each other in azimuth. Figure 3 shows a seismometer module with the remotely operated switch attached. The linkage system between the mass and the data coil of the seismometer results in very nearly linear motion of the coil in the magnet gap. The parallel-linkage mechanism restrains the mass to motion at an angle of 35° 18' to the horizontal.

The switch module is used to remotely select the circuits to be connected to the seven cable leads at the seismometer. Six positions are available:

1. Calibrate module 1, operate centering motor, operate weight lift.
2. Calibrate module 2, operate centering motor, operate weight lift.
3. Calibrate module 3, operate centering motor, operate weight lift.
4. Calibrate modules 1, 2, and 3 in series.
5. Operate hole lock.
6. Operate modules 1, 2, and 3.

With the switch at position 4, the three calibration coils are connected in series and the calibration current is applied by means of the switch motor conductor as shown in figure 4. The diodes, relay, and resistor in the circuit permit the motor to be operated on this lead or permit calibration of all three modules. During calibration, the applied voltage is low and all the current passes through the calibration coils because the relay coil and the Zener diode present a nearly infinite resistance below the Zener break-down voltage. During operation of the motor (at a voltage above the Zener voltage) the current through the calibration coils is limited by the 2700-ohm resistor.

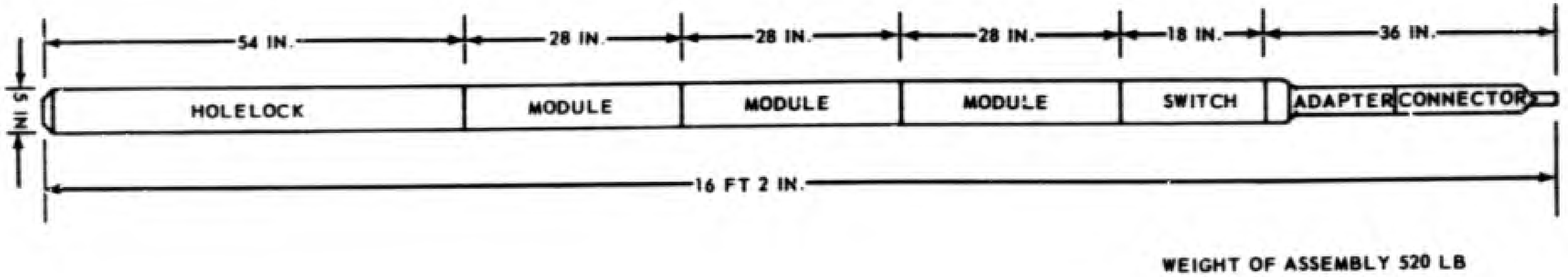

Figure 2. Triaxial seismometer outline drawing

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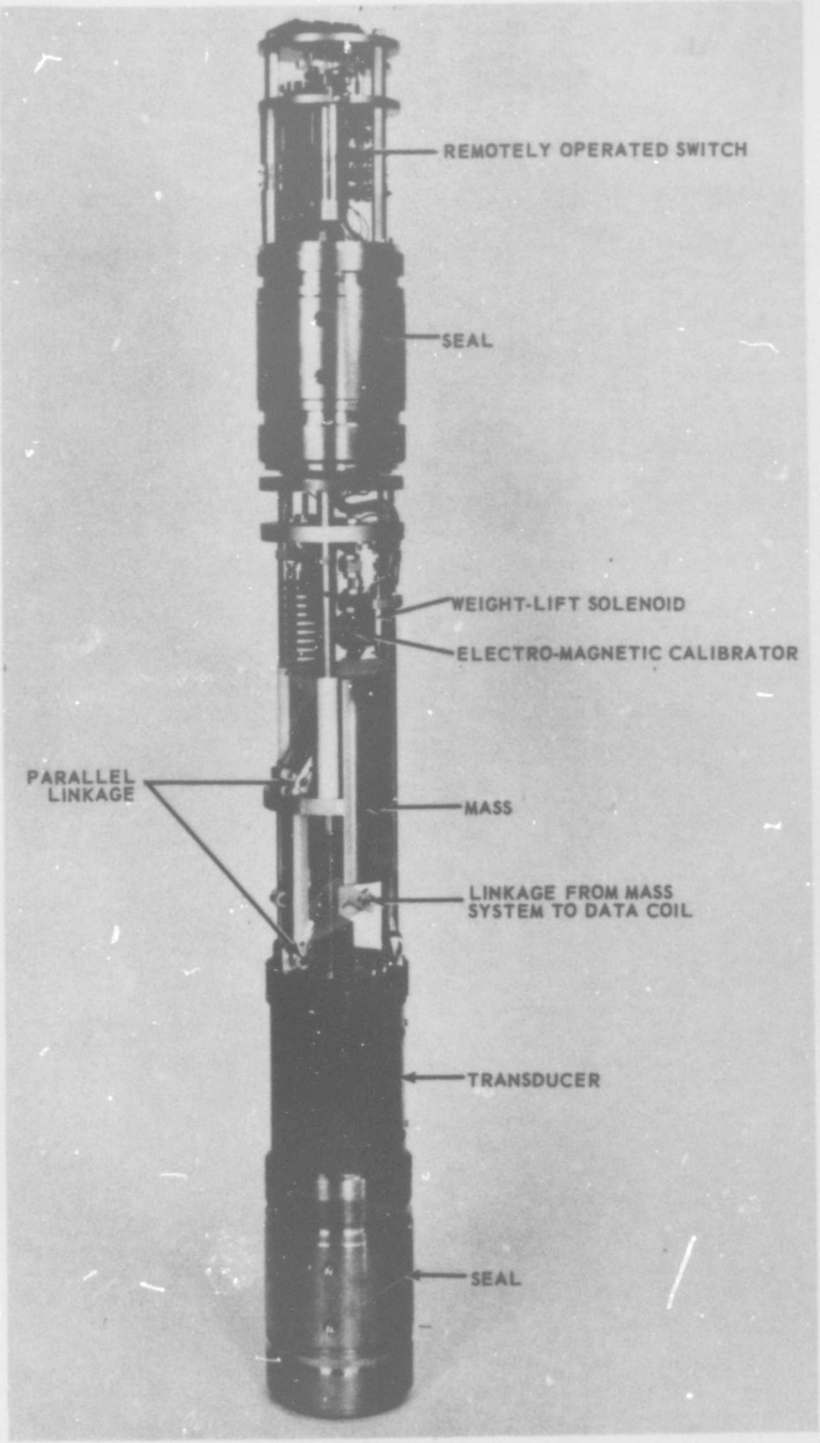

Figure 3. Triaxial seismometer module and switch

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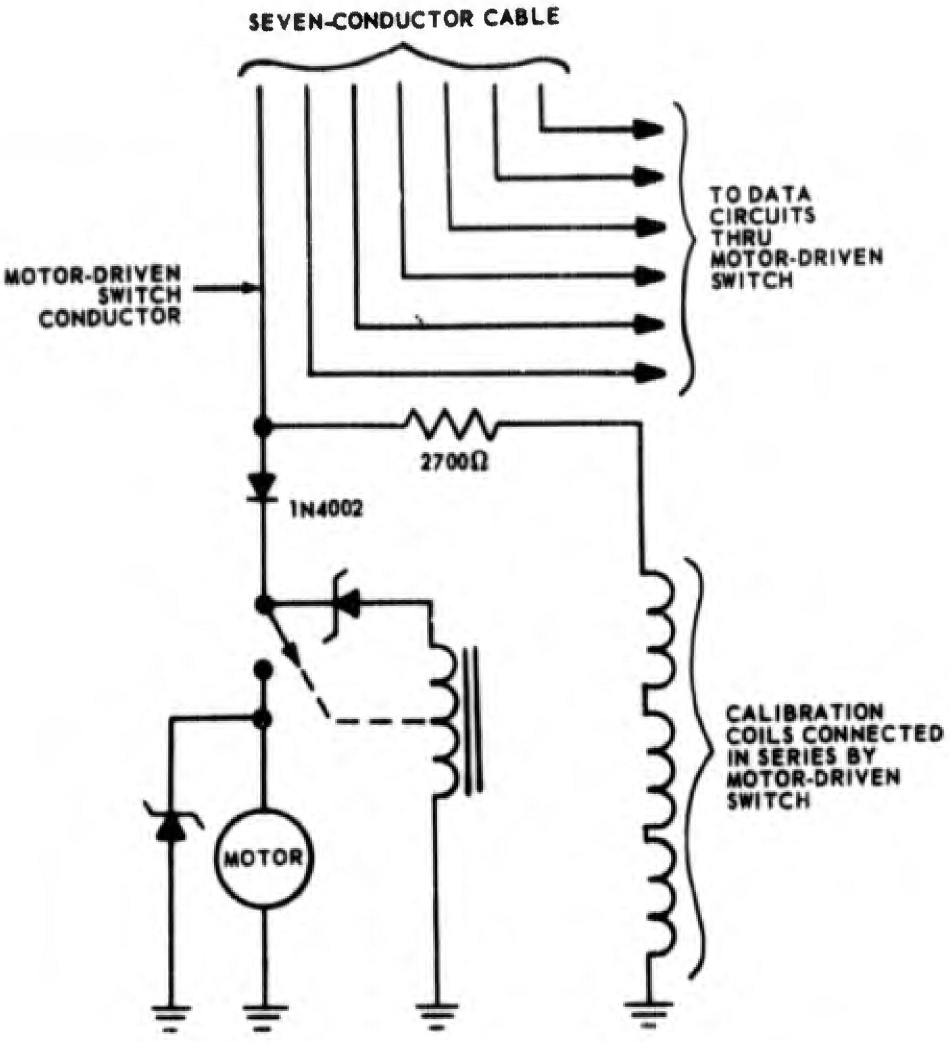

Figure 4. Calibration using motor-driven switch conductor

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3.2 INSTRUMENT SPECIFICATIONS

The preliminary specifications for the seismometer are included as an appendix to this report.

4. LABORATORY TESTS

Tests were performed in the laboratory to verify the performance of the seismometer under controlled conditions. Because the seismometer was intended to be used at high pressure and temperature, considerable effort was expended on tests at environmental extremes.

4.1 FREQUENCY RESPONSE OF PTA USED IN SHAKE-TABLE AND CALIBRATION COIL RESPONSE TESTS

Figure 5 shows the response of the amplifier used in the tests discussed in paragraphs 4.2 and 4.3. The 3 cps galvanometer was damped at 0.7 critical.

4.2 FREQUENCY RESPONSE TESTS

Figure 6 shows a typical response of a module of the seismometer and amplifier at a shake-table amplitude of 30 μp-p. All shake-table tests were conducted using a vertical-motion shake table. Figure 7 shows the calibration coil response of a module of the seismometer. Both responses are in good agreement with the theoretical response.

The electromagnetic coupling between the data coil and the calibrator coil was tested to perform this test, the mass system was locked and the module was shaken at 25 μ p-p. The magnification of the system was raised 32 dB. No resulting output could be detected from the seismometer, indicating that the mass-lock system was adequate. Next, with the mass still locked, a frequency response was run using the electromagnetic calibrator with the PTA and recorder gain raised 32 dB. No measurable output was obtained, indicating that negligible coupling existed between the data circuit and calibration circuit.

4.3 VOLTAGE OUTPUT, DAMPED AND OPEN CIRCUIT

Figure 8 shows the damped output of a seismometer module as a function of frequency as measured from a shake-table test. Comparison with the theoretical response shows a discrepancy around 1 cps. This discrepancy is thought to be the result of an undetected change in damping of the seismometer during the test. Figure 9 shows the open circuit output of the module as a function of frequency, as measured from shake-table and electromagnetic-calibrator inputs.

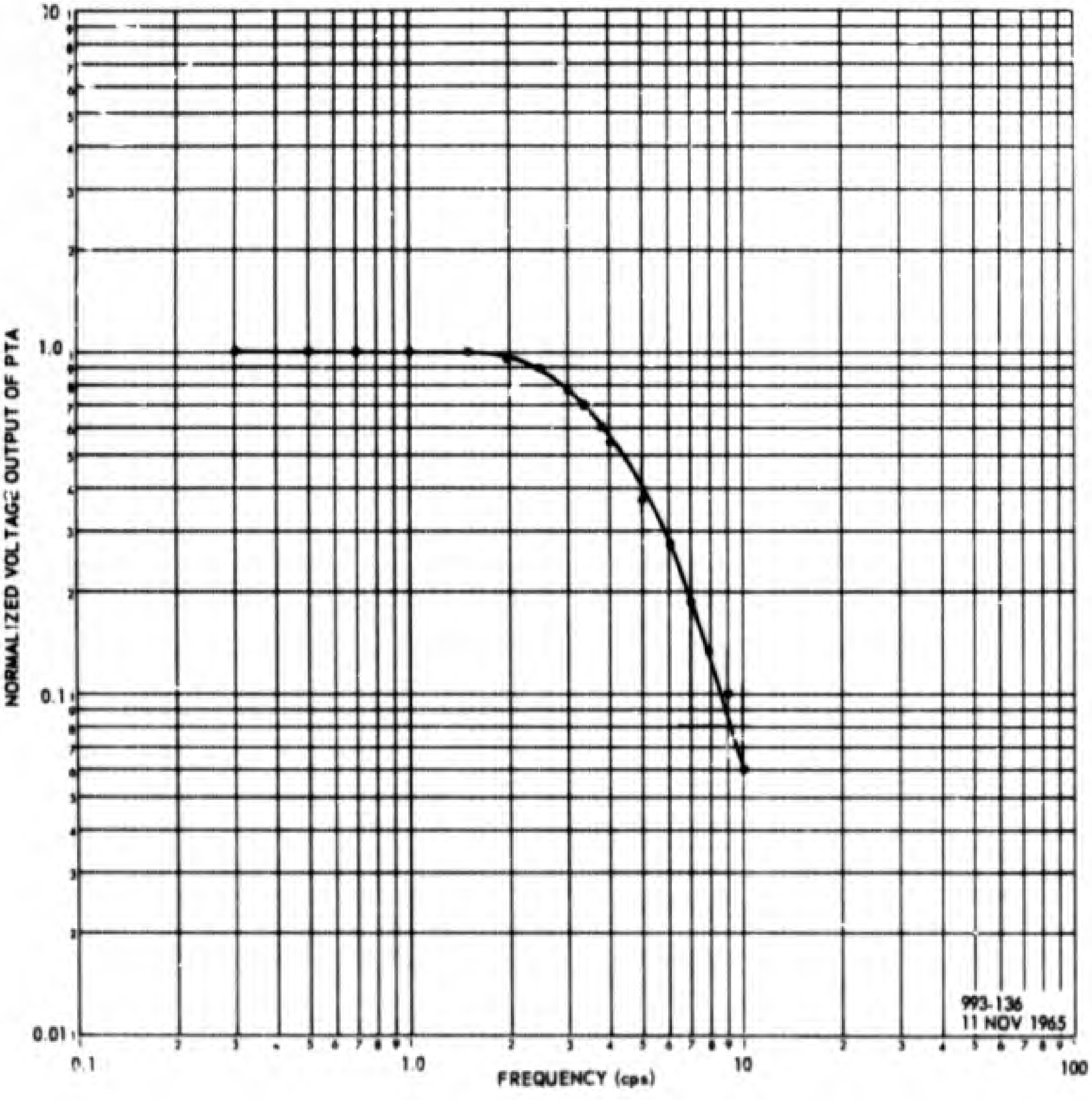

Figure 5. Frequency response of Model 4300 PTA with 3 cps galvanometer and 6824-1 filter. Constant input current. Damped 0.7 critical

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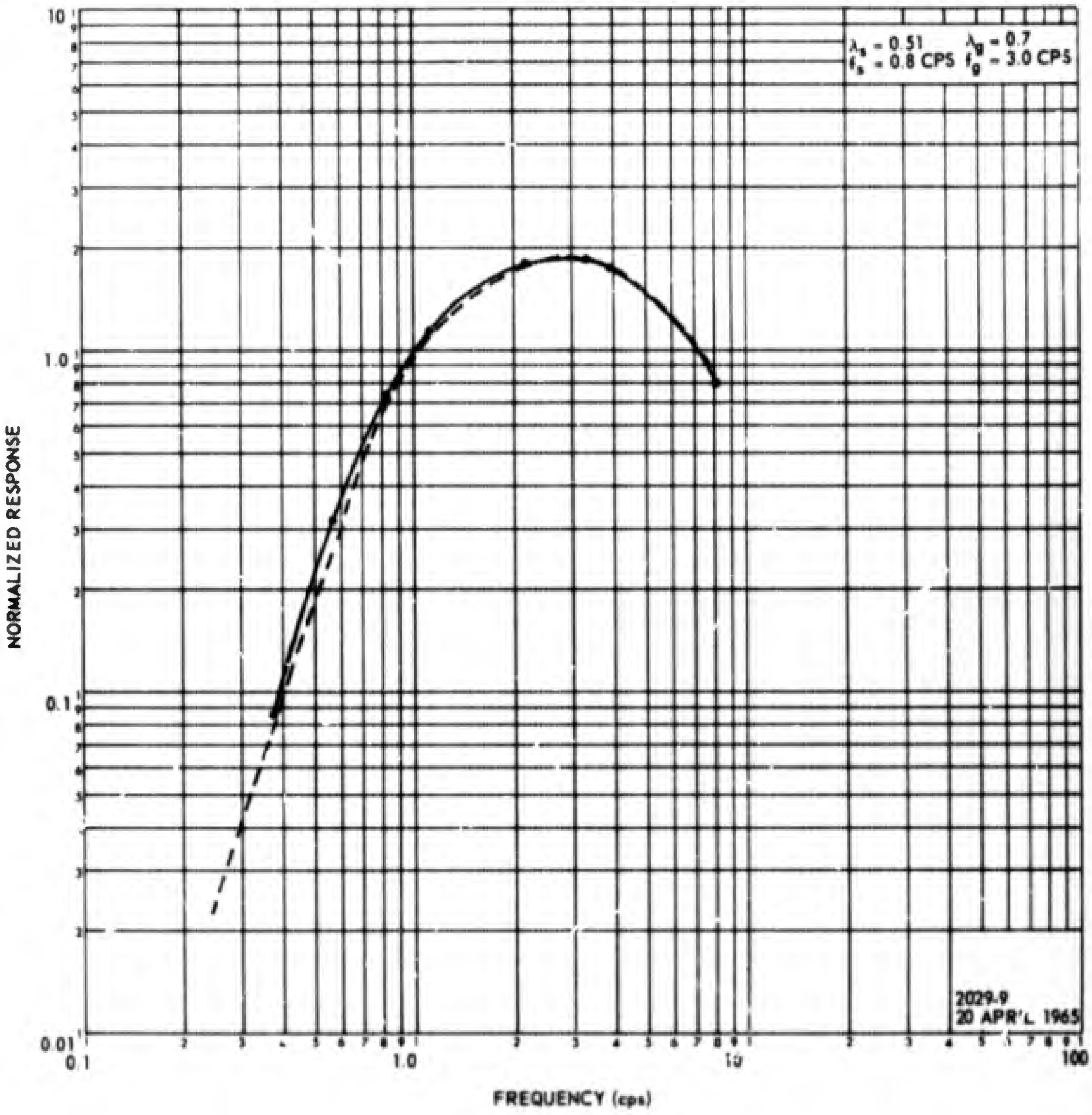

Figure 6. Displacement response of triaxial seismograph obtained from constant amplitude shake-table test. Theoretical response is also shown

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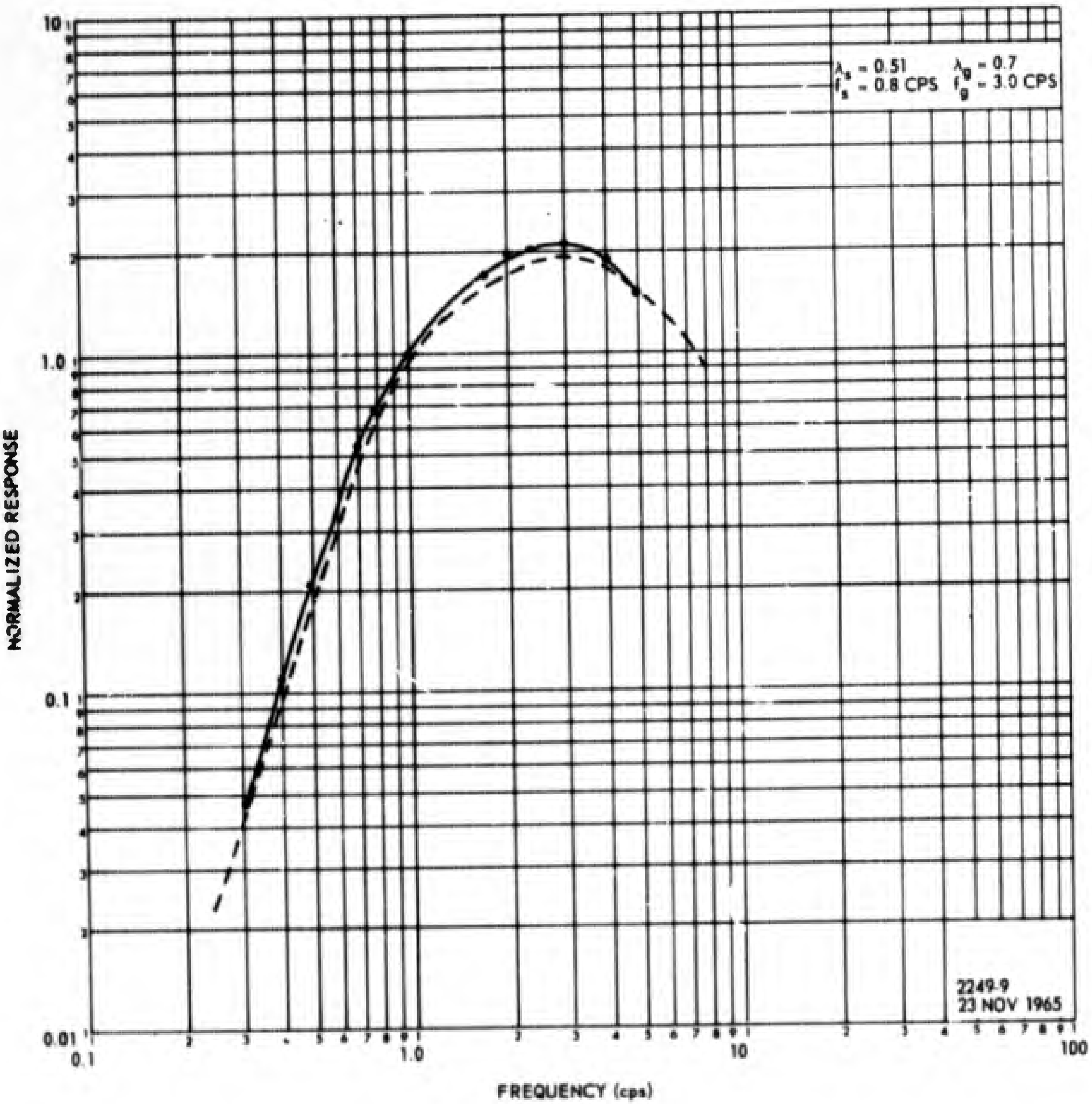

Figure 7. Displacement response of triaxial seismograph obtained with electromagnetic calibrator. Theoretical response is also shown

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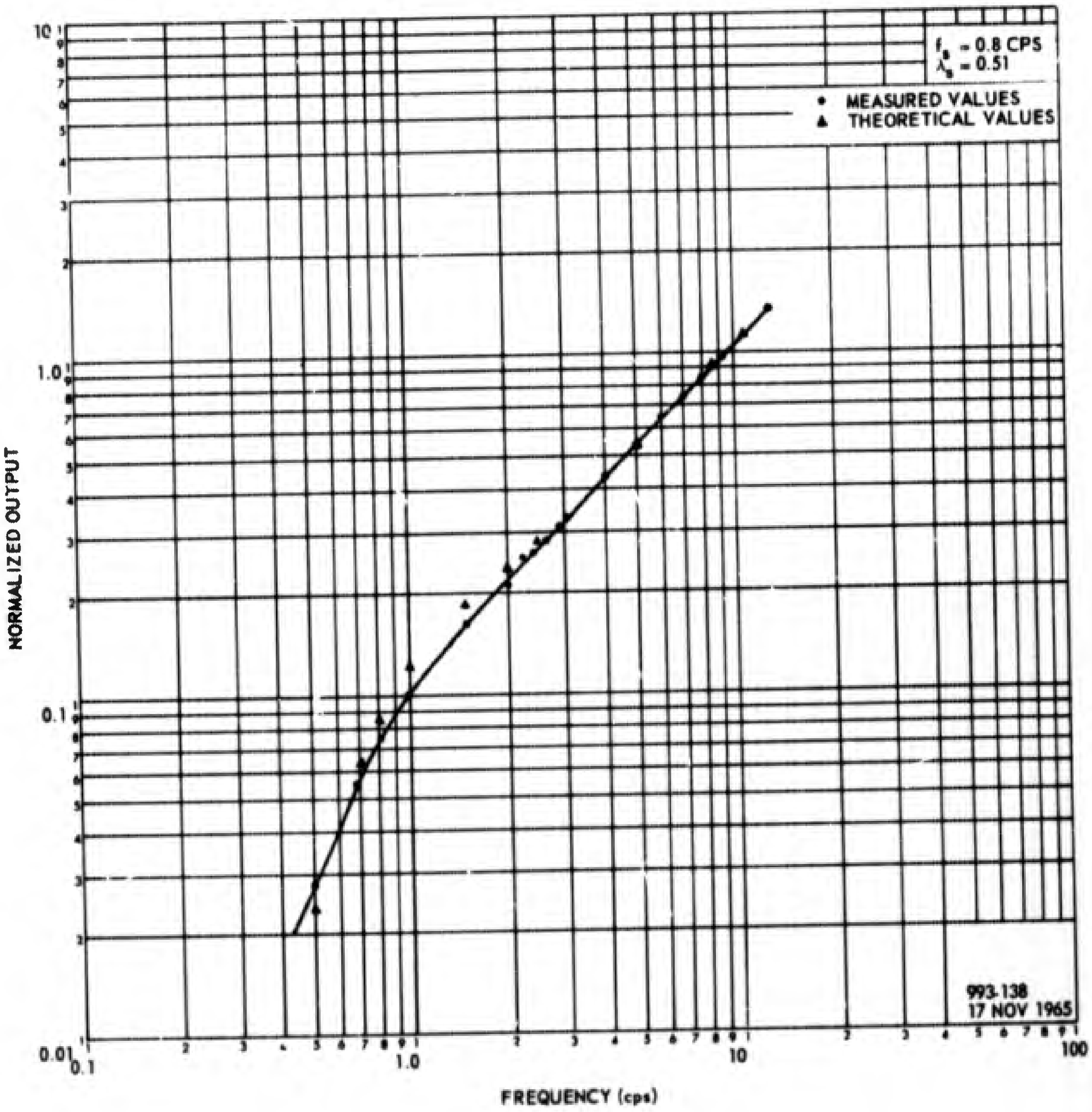

Figure 8. Output voltage of triaxial seismometer obtained from shake-table test

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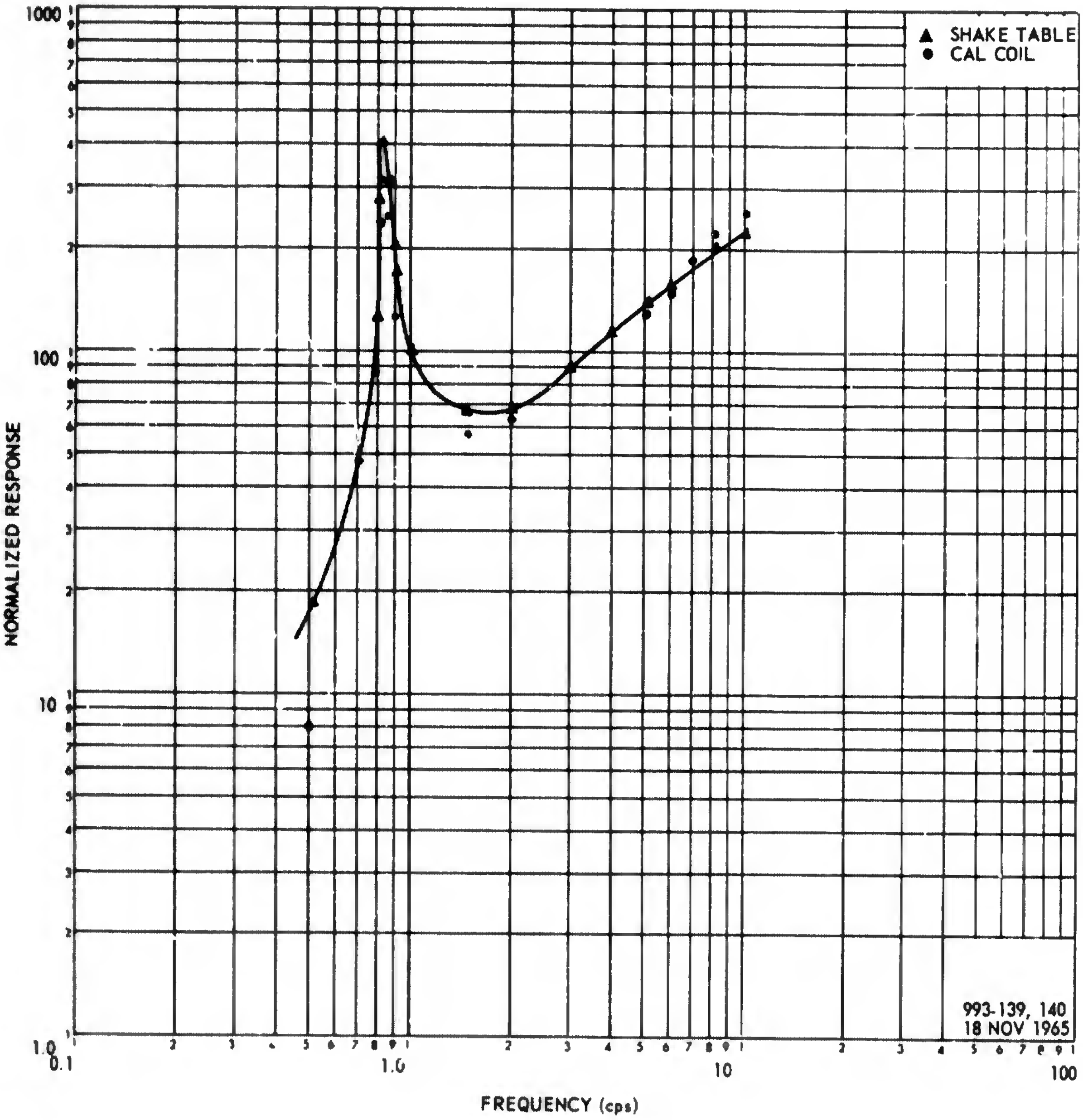

Figure 9. Open circuit output voltage of triaxial seismometer obtained from shake-table and calibration coil inputs

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4.4 PERIOD VS MASS POSITION, PRESSURE AND TEMPERATURE

A module was installed in a pressure-temperature chamber and subjected to selected temperatures and pressures. Because no means existed during this test to accurately determine the mass position, the mass position was estimated from the length of time the centering motor was operated. This procedure led to plots that were not smooth functions, but nevertheless were meaningful when compared with each other. Figure 10 is a family of curves showing free period vs mass position at various pressures. Figure 11 shows the spread in frequency response as determined with the electromagnetic calibrator at all temperatures and pressures. These tests indicate that the seismometer performs as desired.

The family of curves in figure 12, shows mass position vs period at various pressures and temperatures. Figure 13 shows the free period vs mass position before and after the temperature-pressure tests. The close agreement in the curves indicates that the method used to estimate mass position is adequate.

5. FIELD TESTS

5.1 DESCRIPTION OF FIELD SYSTEM AND INITIAL FIELD TESTS

Two triaxial seismometers were operated at a test site near Grapevine, Texas (GV-TX). One seismometer was operated in a deep hole at a depth of 2135 m and another at a depth of 152 m in a shallow hole. Recordings were made on a Develocorder and on a magnetic-tape recorder. The signals recorded included the direct output of each module (through a phototube amplifier) the summed output of the three modules at the output of the phototube amplifier, and the output of a Coordinate Transformer, Model 16432. A block diagram of the system is shown in figure 14 and a seismogram is shown in figure 15.

The triaxial seismometer was also operated at the bottom of a sub-surface tank, 6 m deep by 2 m diameter (20 ft x 6 ft). A three-component set of short-period seismometers, Model 18300, was installed and operated adjacent to the triaxial seismometer as a reference. The reference seismographs had responses as shown in figure 16. Figure 17 shows the response of the seismograms to the background noise at the Grapevine test site. As can be seen, the seismograms are in excellent agreement.

Figure 18 shows a reproduction of an event recorded by the triaxial seismograph and the reference vertical seismograph. The reproduction was made from an analog tape recording and processed by the technique described in Technical

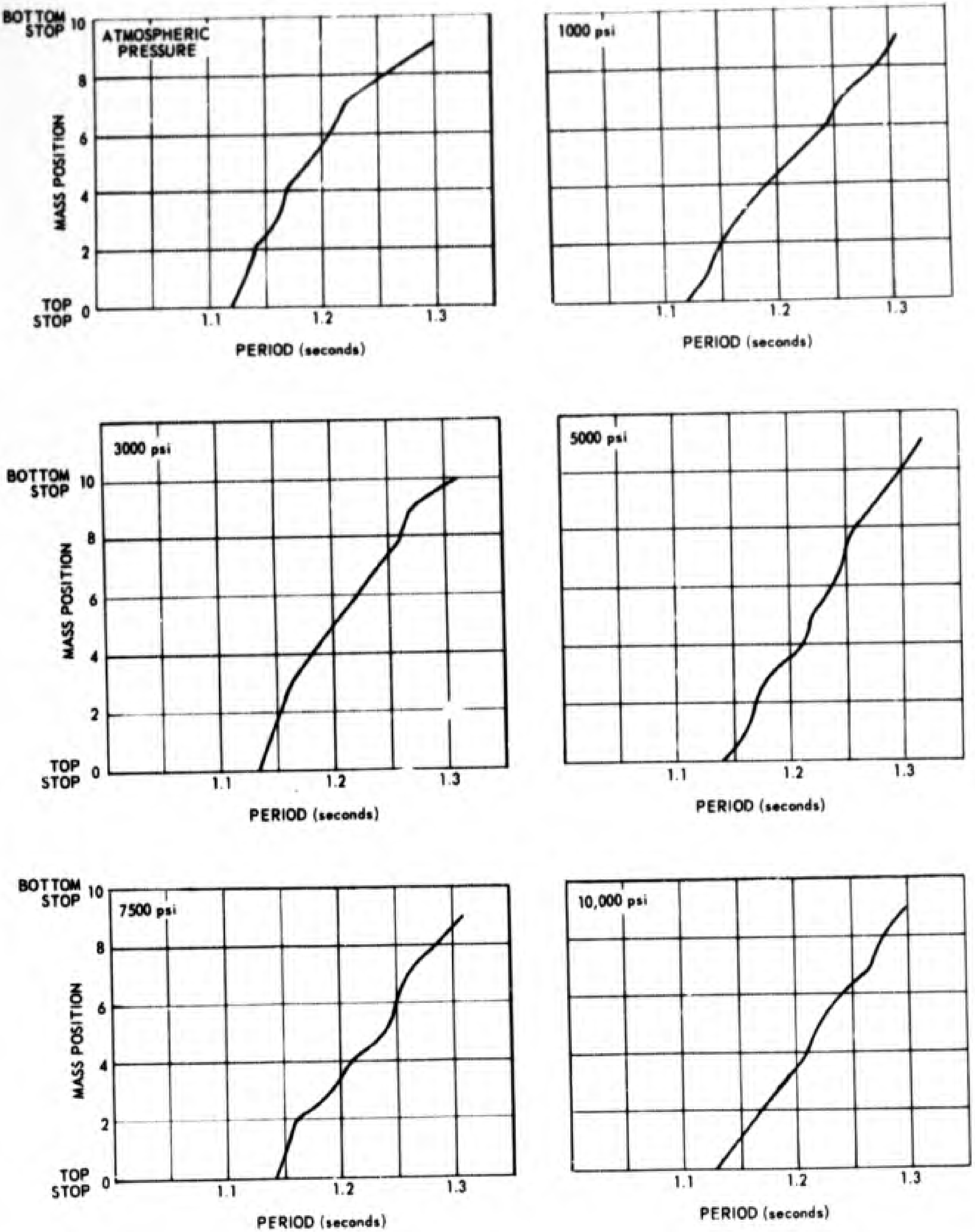

Figure 10. Mass position vs period of triaxial seismometer at six different pressures

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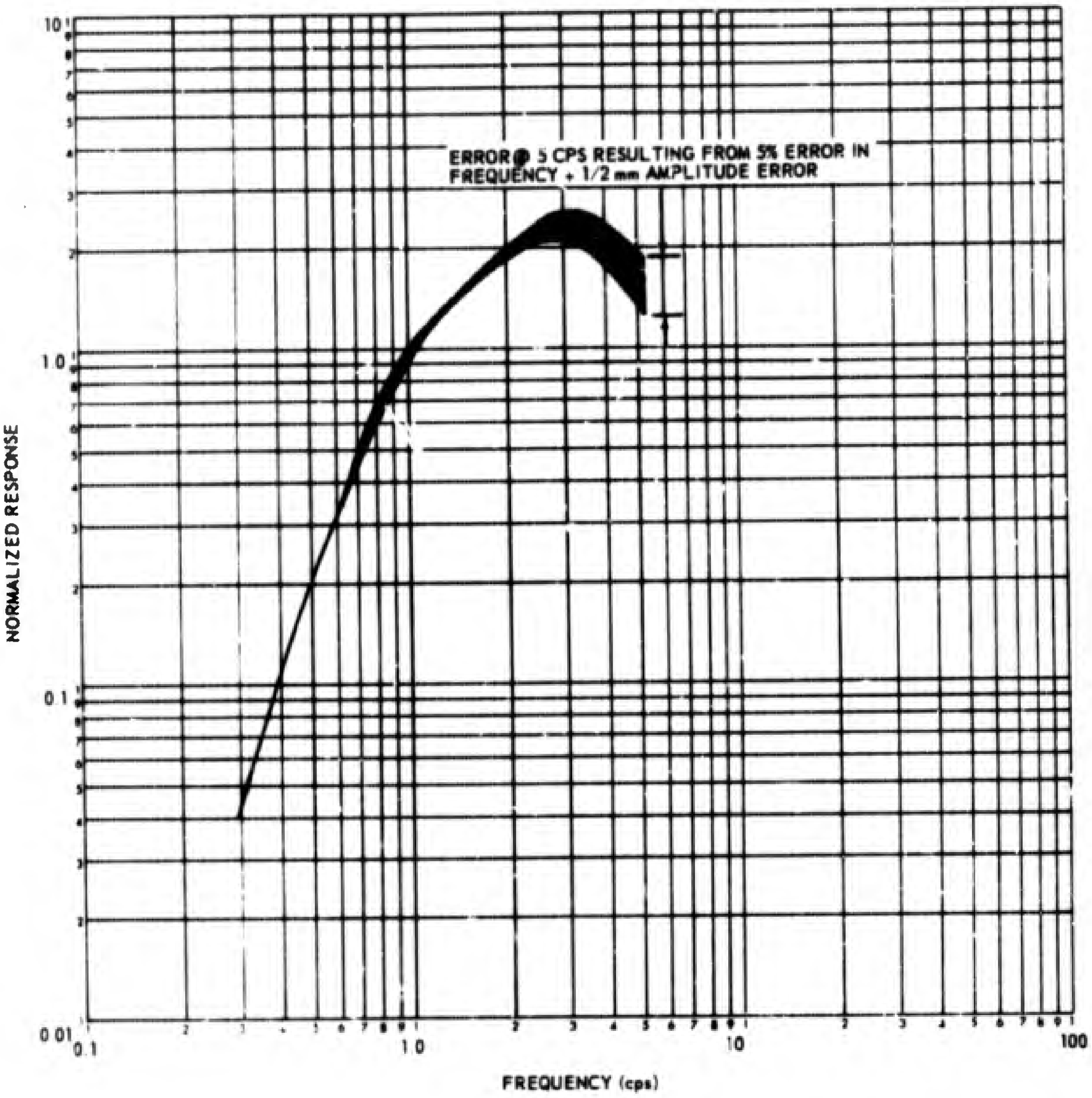

Figure 11. Normalized frequency response at various pressures and temperatures

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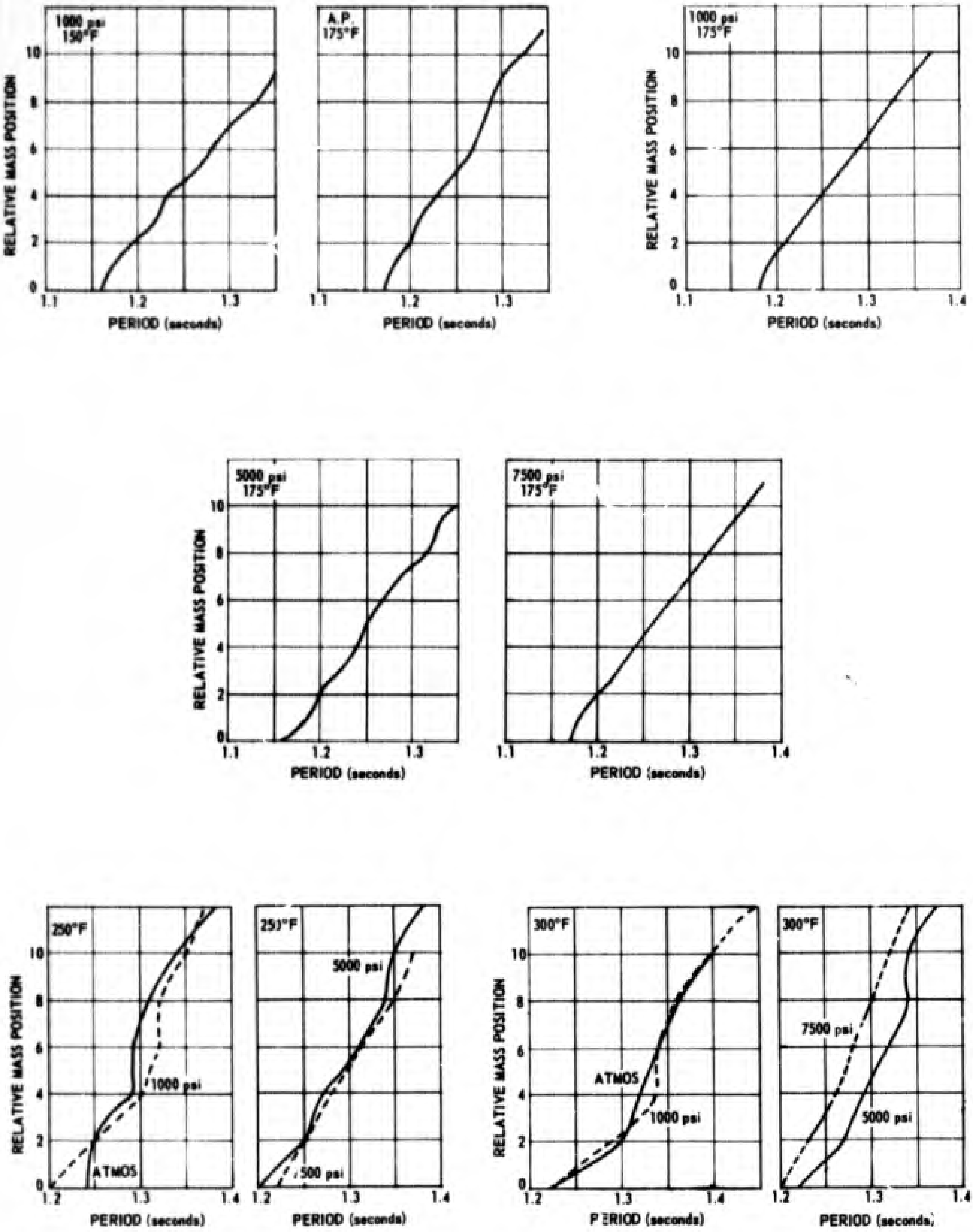

Figure 12. Mass position vs period of triaxial seismometer as a function of temperature and pressure

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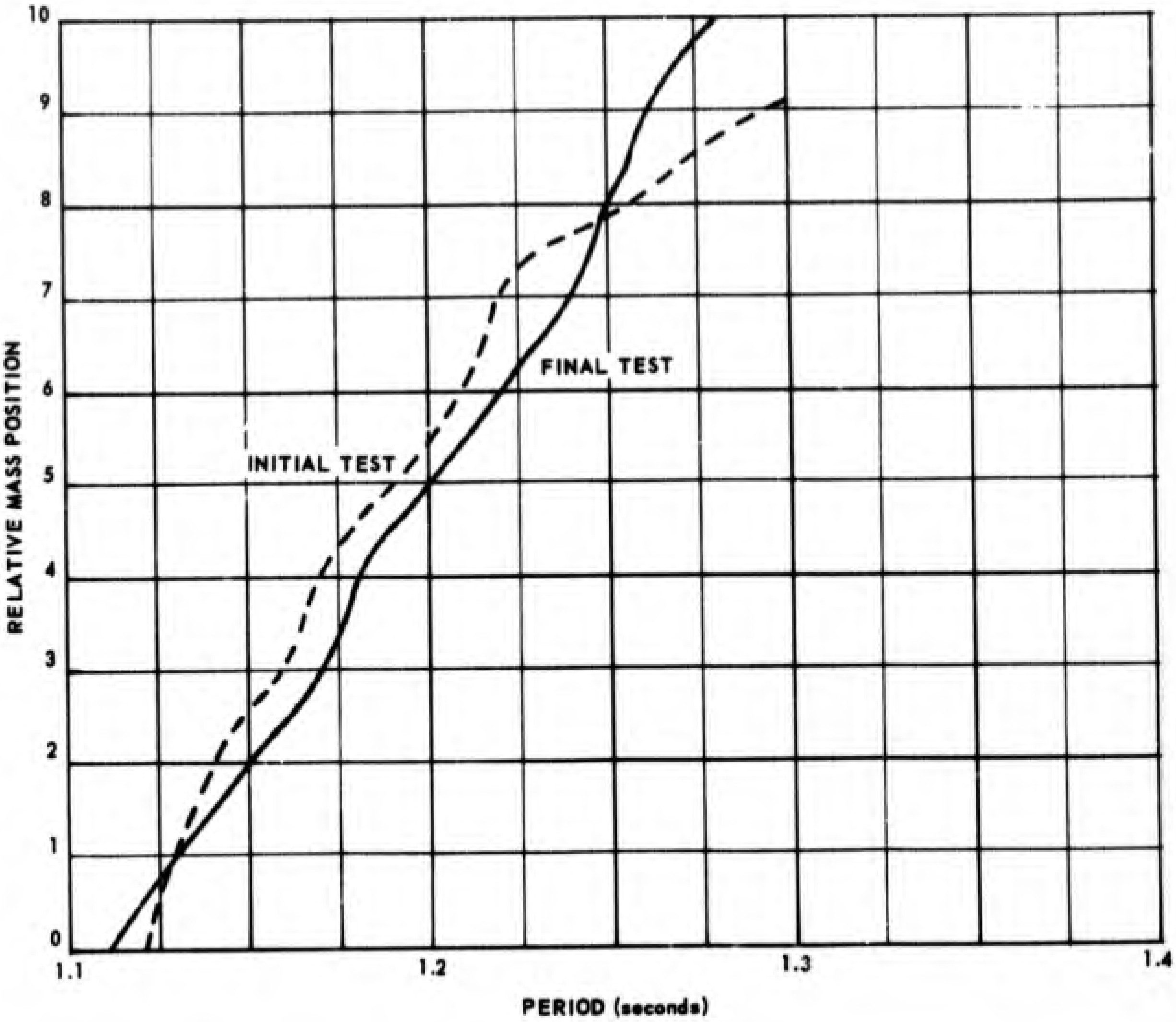

Figure 13. Comparison of free period vs mass position before and after pressure-temperature tests. Triaxial seismometer

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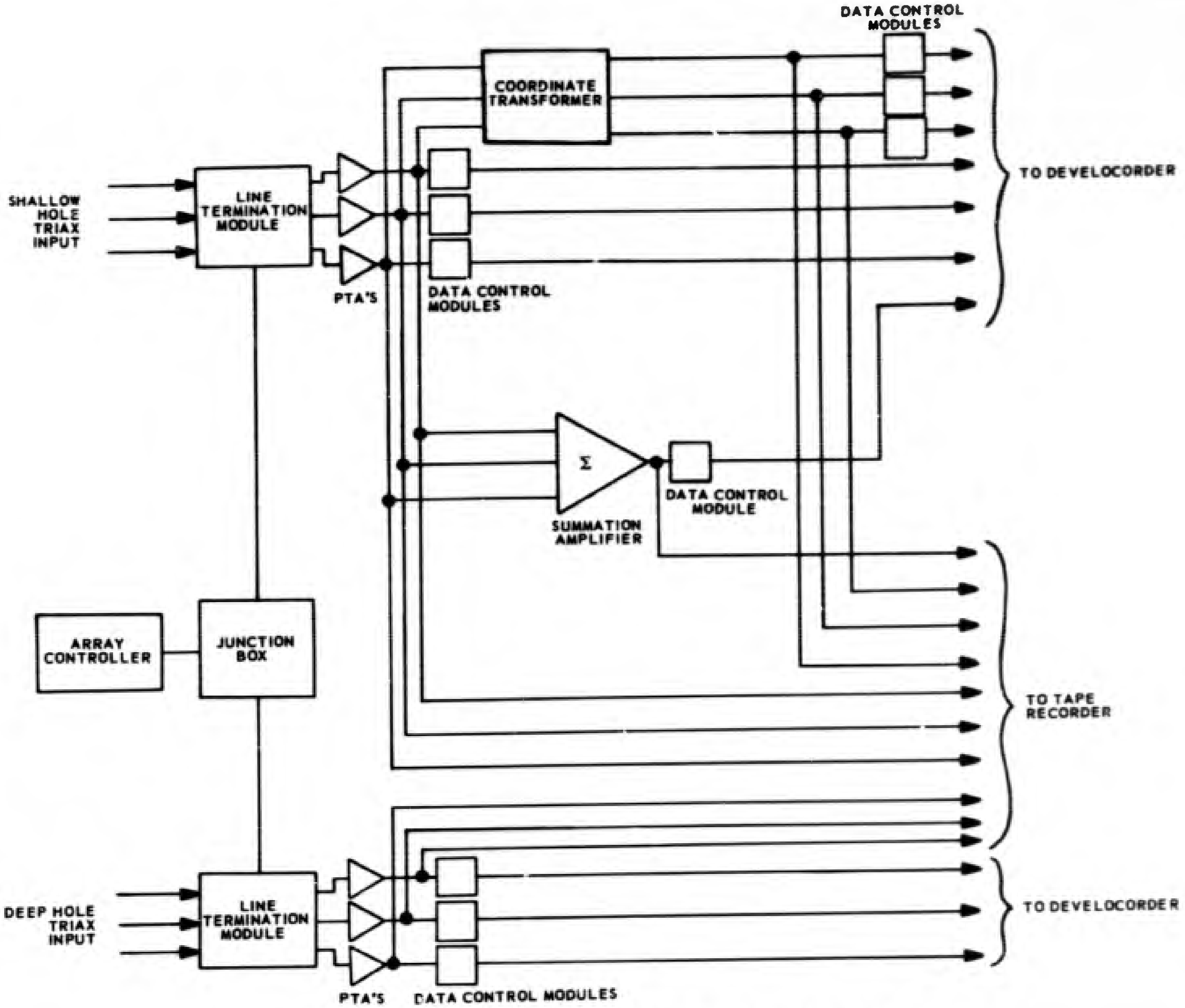

Figure 14. Triaxial array at Grapevine site

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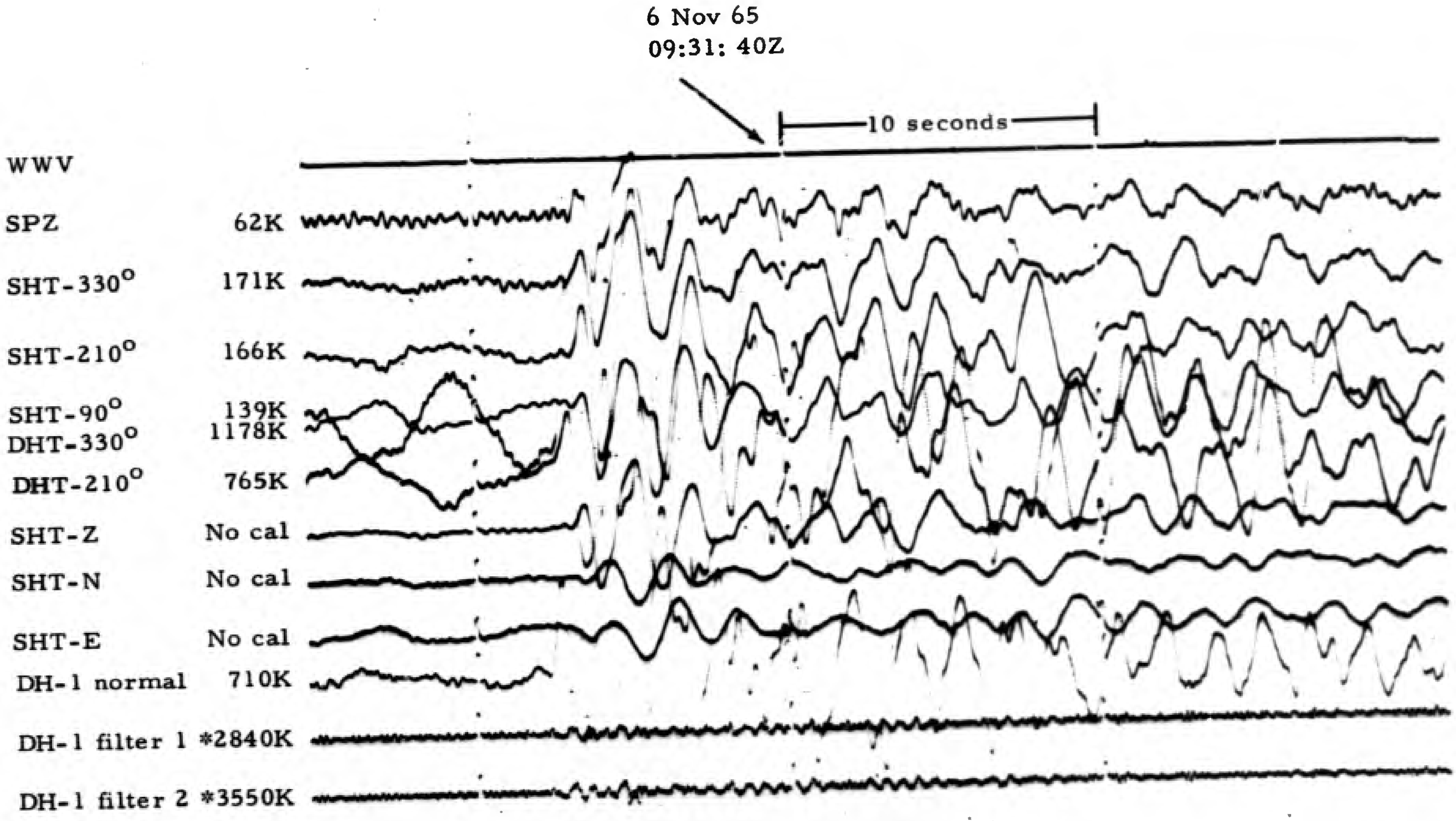

Figure 15. Recording of an event by a surface vertical seismograph (SPZ), deep-hole vertical seismograph (DH-1), shallow-hole triaxial seismograph (SHT), and deep-hole triaxial seismograph (DHT), at Grapevine, Texas. Epicenter unknown. Magnifications at 1 cps except those marked *, at 10 cps. (X10 enlargement of 16 mm film.) Shallow-hole triaxial at 153 m, deep-hole triaxial at 2135 m and deep-hole vertical at 2901 m. SHT-Z, SHT-N, and SHT-E are coordinate transformed outputs of SHT-330°, SHT-210°, and SHT-90°

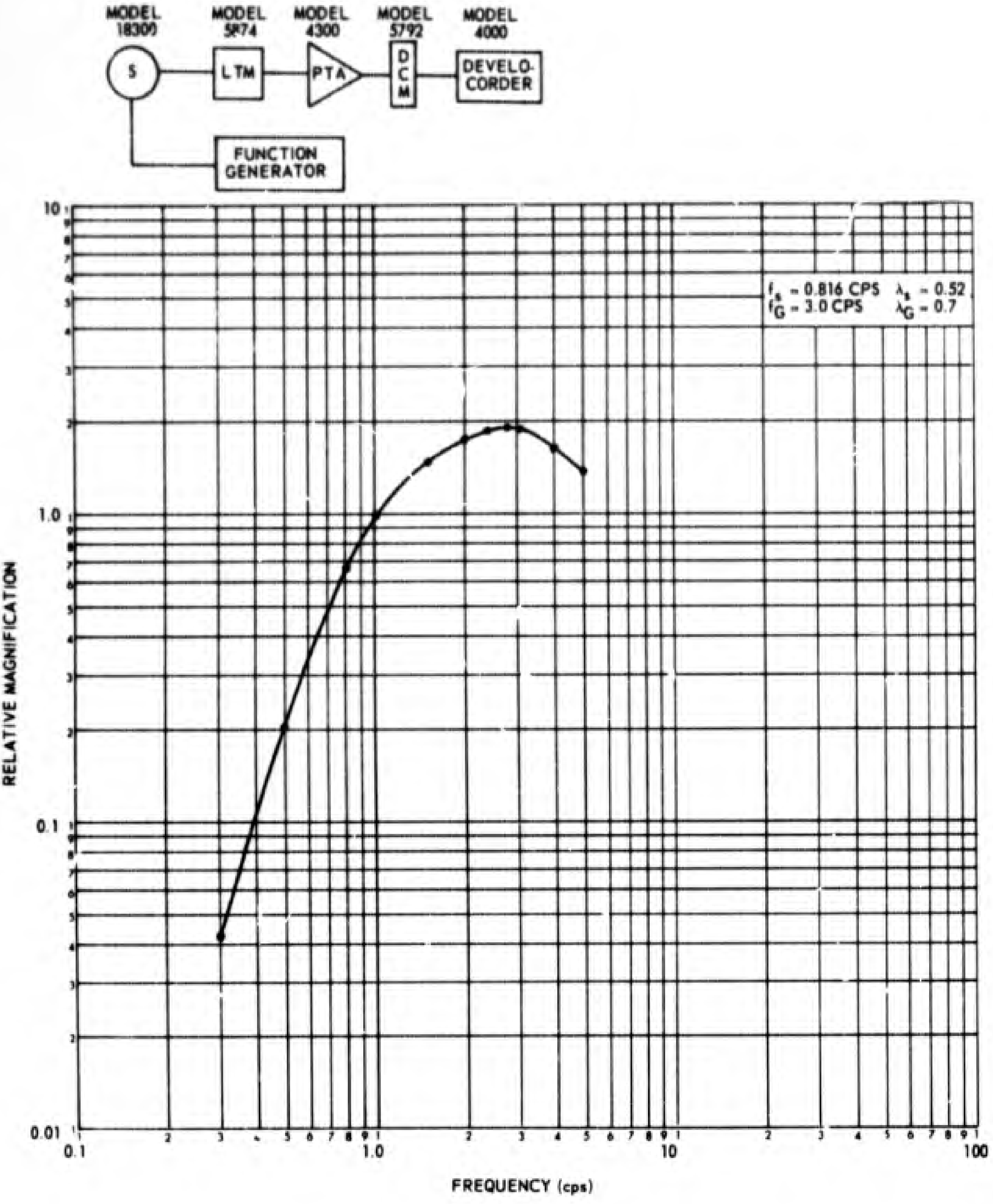

Figure 16. Displacement response of reference seismograph (Z) at GV-TX. Response normalized to unity at 1 cps

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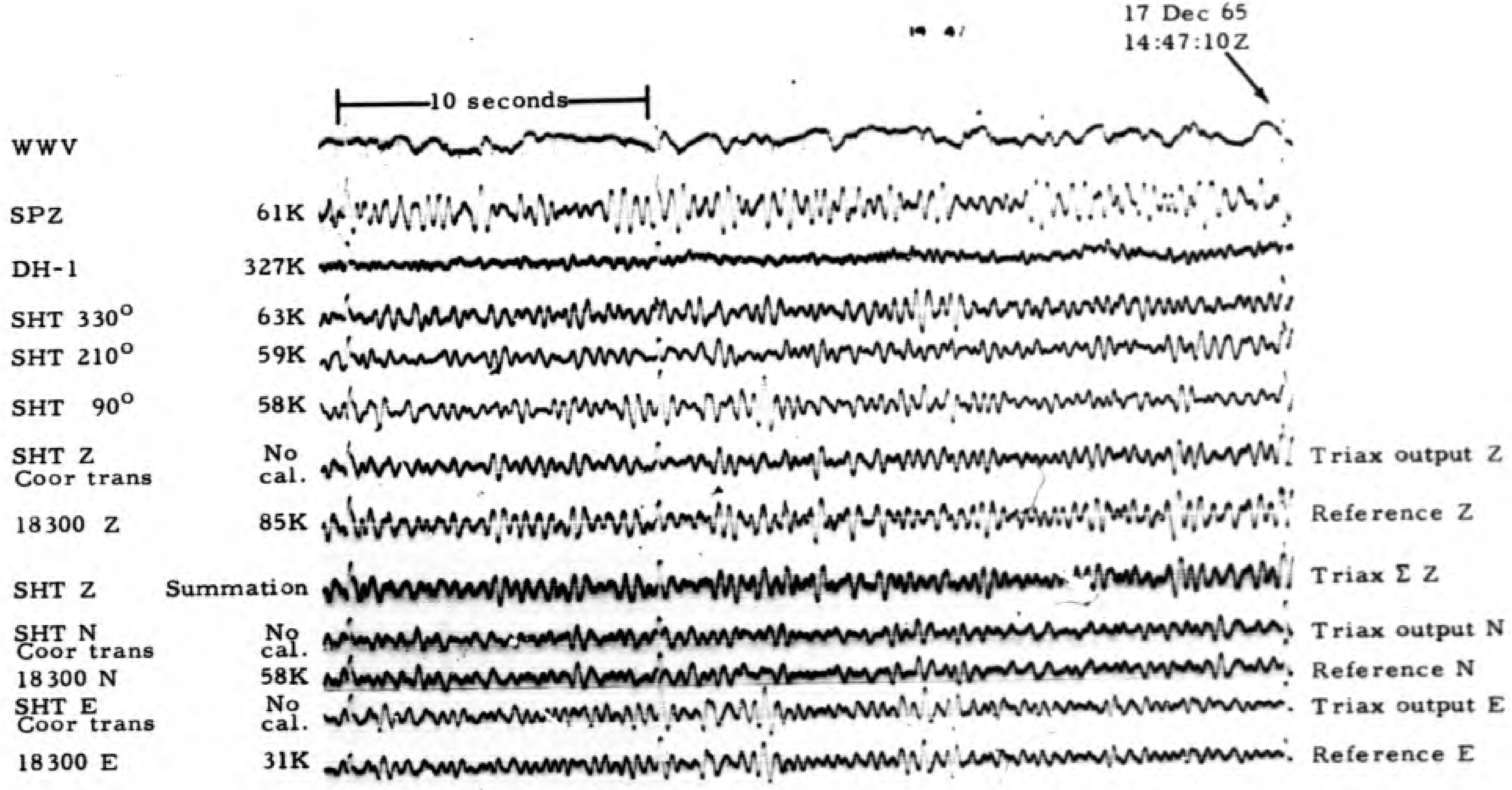

Figure 17. Recording of noise by surface vertical seismograph (SPZ); deep-hole vertical seismograph (DH-1), shallow hole triaxial seismograph (SHT), coordinate transformed triaxial seismograph, and the Model 18300 reference seismograph at Grapevine, Texas. Magnifications at 1 cps (X10 enlargement of 16 mm film). DH-1 at 2901 m.

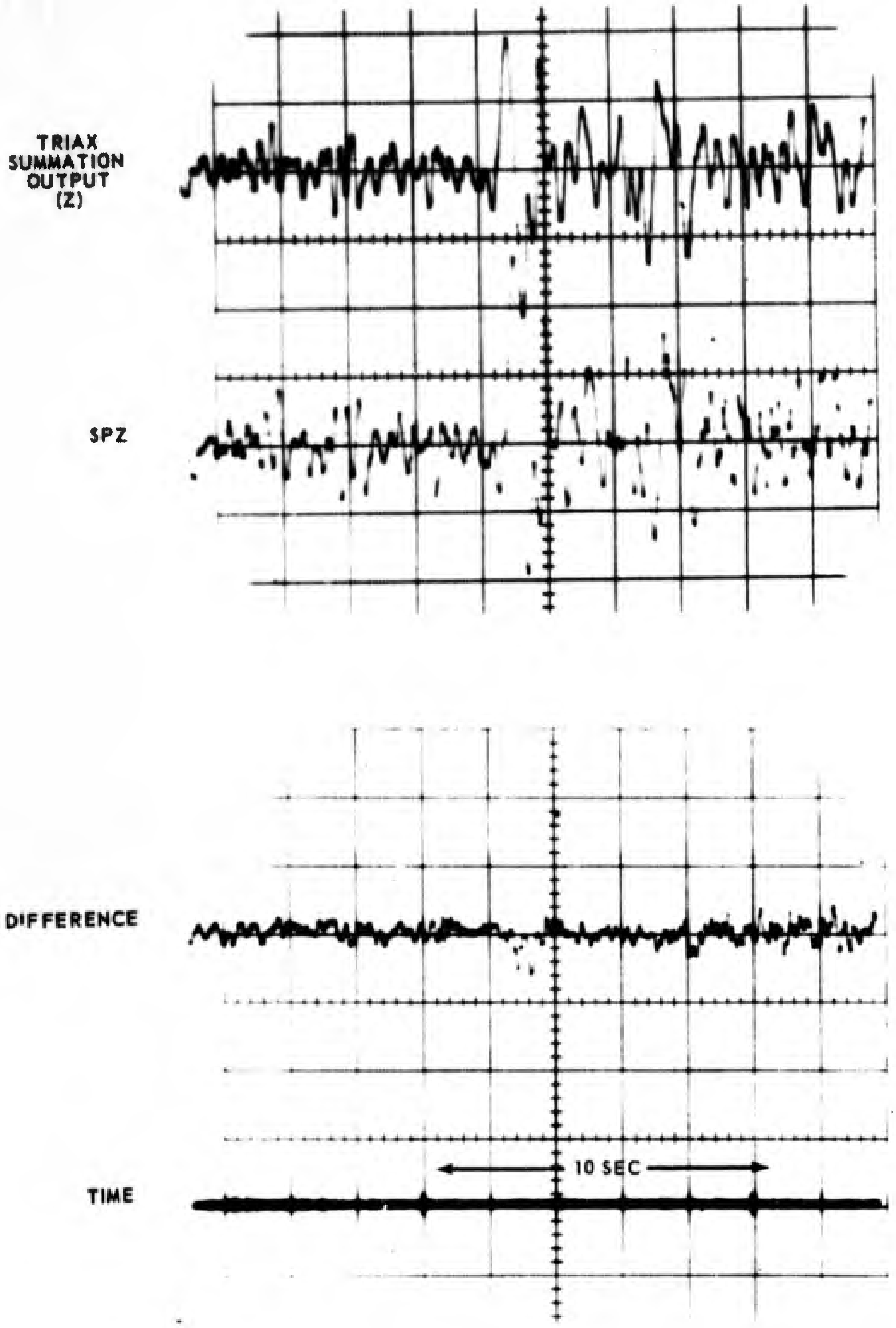

Figure 18. Signals recorded by triaxial seismograph and conventional seismograph

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Report No. 64-108. Also shown in figure 18 is the result of subtracting one signal from the other. The vertical and horizontal scales are the same for both illustrations. The cancellation of the signals shows that the two seismographs have nearly identical response. The two small pulses shown in the difference trace are the result of minute differences in response or small differences in coupling to the earth. The reference seismometer was on the floor of the tank whereas the triaxial seismometer was clamped to the tank's wall.

5.2 FURTHER FIELD TESTS

The triaxial seismograph was moved to a test site near Apache, Oklahoma (AP-OK), where it was installed in a deep hole with two additional systems. A fourth system was installed in a shallow hole. Routine field operations are planned for the seismographs.

6. CONCLUSIONS

The deep-hole symmetrical triaxial seismometer has been designed, built, and laboratory tested. Preliminary field tests indicate that it is a useful instrument and will be of value in this research program.

ACKNOWLEDGEMENT AND ADMINISTRATION

The deep-hole symmetrical triaxial seismometer was initially developed in Project VELA T/072. The design concepts, linkage design, and general configuration were the result of work done by R. E. McMillan of Geotech.

Design improvements were made to the seismometer in Project VELA T/5051. Those engaged in this work included:

Richard M. Shappee, Program Manager
Robert F. Knight, Project Engineer
John R. Wise, Engineer

APPENDIX to TECHNICAL REPORT NO. 66-67

PRELIMINARY SPECIFICATIONS
DEEP-HOLE SYMMETRICAL TRIAXIAL SEISMOMETER, MODEL 22700

PS-22700
21 December 1964

GEOTECH PRELIMINARY SPECIFICATIONS

DEEP-HOLE SYMMETRICAL TRIAXIAL SEISMOMETER, MODEL 22700

PURPOSE

The Deep-Hole Symmetrical Triaxial Seismometer, Model 22700, is a three-component seismometer capable of operation in deep holes. It contains three short-period inclined seismometer modules and associated control equipment mounted in interconnected cylindrical pressure cases. The modules are stacked vertically. Each module is a complete moving-coil seismometer, inclined 35.3 degrees from the horizontal, with an undamped natural frequency of 0.8 Hz and an inertial mass weighing 5 kg. The sensitive axes are mutually perpendicular. Each module has independent provisions for remotely centering and mass locking. A motor actuated switch, allows selection of various electrical circuits from the surface.

OPERATING CHARACTERISTICS

Each module:	
Natural frequency	0.8 Hz
Inertial mass	5 kg (weight)
Mass travel	±5 mm
Calculated internal noise	6.1×10^{-12} m earth motion equivalent at 423°K and 0.8 Hz
Generator constant	150 Vsec/m
Coil resistance	310 Ω at 25°C
Average flux	0.32 T
Critical damping resistance	350 Ω at 25°C
Tilt	10° from vertical max
Calibrator	Electromagnetic and weight lift
Instrument package:	
Temperature	150°C max
Pressure	5.2×10^{7} N/m max

Other environment factors in accordance with DSE-4 where applicable.

POWER REQUIREMENTS

Input	3 W max 28 Vdc intermittent (for each motor)

PHYSICAL CHARACTERISTICS

Each seismometer module	
Height	0.71 m
Diameter	126 mm
Weight	39 kg
Instrument package (less hole lock and connector)	
Height	2.6 m
Diameter	126 mm
Weight	135 kg
Instrument package (with Hole Lock, Model 13900, and Schlumberger adapter and connector)	
Height	6.3 m
Diameter	126 mm
Weight	236 kg

CONNECTORS

None furnished. Requires Schlumberger CIS-B connector and Geotech Cable-Head Adapter Kit, Model 22482, or Geotech Adapter Assembly, Model 22520, and Geotech Connector, Model 22503.

ACCESSORIES

Hole Lock, Geotech Model 13900

NOTE: The fittings and accessories for this instrument are interchangeable with the Short-Period Deep-Hole Seismometer, Model 11167-1.

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3. REPORT TITLE

Deep-Hole Symmetrixal Triaxial Seismometer, Model 22700

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Test report of instrument

5. AUTHOR(S) *(Last name, first name, initial)*

Shappee, Richard M.

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13. ABSTRACT

A deep-hole symmetrical triaxial seismometer was designed, laboratory tested and field tested. The results of tests showed that the instrument met the design objectives and was ready for additional field testing and use. (U)

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Deep-hole symmetrical triaxial seismometer						
Project VELA T/5051						
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